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QUARTERMASTER RESEARCH & ENGINEERING COMMAND
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EFFECTIVE AREA OF CLOTHED MAN FOR SOLAR RADIATION

QUARTERMASTER RESEARCH & ENGINEERING CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

JULY 1961

NATICK, MASSACHUSETTS

AD- Div. 28 Accession No.

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2. Heat production
3. Absorption
4. Body surface
5. Posture
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EFFECTIVE AREA OF CLOTHED MAN FOR SOLAR RADIATION

John R. Breckenridge

Biophysics Branch

Project Reference:
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FOREWORD

This paper presents long-needed information on one of the factors which determine the heating effect of sunlight on the clothed man. Solar heat load is a major consideration in hot environments and has frequently been studied. It receives much less attention in cold environments, since the amount of heating seems to be small. This impression is unfortunate, since important benefits might result if the study of clothing requirements for maximal effect of sunlight in cold climates were emphasized. The data on effective area in the path of sunlight (cross-section normal to the sun's rays) given here may provide the needed stimulus, since they show that appreciable amounts of radiation are available if only the scientist can devise ways of making this radiation more efficient. Similar data for hot-weather clothing should also be valuable since they will permit more accurate separation of solar load from other environmental loads than has heretofore been possible.

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ABSTRACT

The effective, or normal cross-sectional, area in the path of direct sunlight was determined for average-sized men dressed in each of 3 uniforms (standard Arctic, wet-cold, and hot-weather uniforms), and in each of 4 positions (sitting, standing, walking, and prone). Values were obtained by measuring the outlined areas of the men on photographs taken from various directions (front, rear, side, overhead), assuming that a camera located between the sun and man would photograph the same cross section as that in the path of direct radiation. Front, side, and rear views were taken at camera angles with the horizontal of 15°, 30°, 45°, 60°, and 75°, and overhead views were taken (camera angle, 90°).

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EFFECTIVE AREA OF CLOTHED MAN FOR SOLAR RADIATION

1. Introduction

Attempts to estimate the heating effect of solar radiation on the clothed man have not been very successful, partly because of a lack of information on the effective area exposed to radiation. This area, which determines the amount of direct radiation falling on the clothing, depends on such variables as type and bulkiness of clothing, posture, and solar angle. Other factors are involved in solar heating, such as fabric absorption characteristics and the efficiency of the radiation absorbed, but these can be established with reasonable accuracy. The percent of radiation absorbed can be estimated from reflectance data, applying corrections for color, as determined in previous work (2). However, the assumption that solar radiation is absorbed only at the surface of the clothing can lead to serious errors since, as shown by Pratt (4), absorption can occur beneath the surface, resulting in increased heating efficiency. For the type of uniforms considered here, it can be assumed that nearly all the radiation is absorbed at the surface, and efficiency of the radiation can be calculated from insulation data (3); these insulation data are available for many types of clothing over a wide range of wind speeds (1).

This study was conducted to obtain effective area data on Arctic, wet-cold, and hot-weather uniforms, supplementing work on nude men done several years ago (5). The investigation covered subjects in sitting, standing, walking, and prone positions, and was limited to average-sized subjects. The data were obtained from photographs of the subjects and of a beach ball used as reference sphere, taken at angles with the horizontal ranging from 15° to 90°; it was assumed that the image areas were representative of the effective areas for sunlight passing through the camera position (i.e., with the sun, camera, and subject in line).

2. Theory

The effective area for direct sunlight on a man is equal to the cross section in the path of the sun's rays. This is identical with the area of shadow cast on a plane surface at right angles (normal) to the sun's rays. Thus it is seen that effective area is not the area of skin or clothing which is illuminated. A camera placed between, and in a line with, the sun and the man will photograph the same cross section if the camera is used at a sufficient distance from the man. This distance is theoretically infinite (since the sun's rays are parallel) but much shorter distances can be used without serious parallax errors. The effective area for a given sunlight direction can therefore be determined by measuring the areas of the man and of a sphere on a photograph taken from this direction and computing the effective area from these data and the known diameter of the sphere.

3. Procedure

The method, which has been described elsewhere (5), consisted of photographing two average-size soldiers (5' 11", 180 lbs) alongside a large beach ball, then, with a planimeter, measuring the image areas on 8" x 10" enlargements. The men's cross-sectional areas were then computed using multiplying factors indicated from the reduction in size of the beach ball (ratio of image area to actual cross-sectional area). Photographs were taken from the front, side, rear, and overhead with the men sitting, standing, and simulating walking, and from the front, side and overhead for a prone position, at camera angles with the horizontal of 15° to 90°, in 15° increments. One complete series of exposures was made with the standard Arctic uniform, another with the wet-cold uniform, and a third with the hot-weather utility uniform.

The photographs were taken from a fire escape, with the subjects on the grass next to it. Camera-to-subject distance was kept at about 25 feet by shifting the subjects whenever the camera was moved to change the angle. This distance was less than ideal but had to be used to obtain reasonably large images, since a telephoto lens was not available and only limited enlargement of the negatives was possible. Calculations showed that the effective area probably could not differ from that thus photographed by more than 2% under the most adverse conditions, whereas this error could easily have been exceeded if area measurements on small images were attempted. The usual procedure with each uniform was to position the camera and subjects with the aid of a clinometer, take a complete series of views and poses, then proceed to the next larger angle. For a typical photograph, the two subjects were the same type of clothing and were similarly posed, facing in the same direction. The use of two subjects helped to average out individual differences in clothing drape, pose, etc. The beach ball was anchored on the ground between the subjects at their average distance from the camera. A typical photograph of the subjects and ball is shown in Figure 1, and illustrations of the four poses are shown in Figure 2.

Extreme care was used in measuring the images, particularly those of the ball, which were rather small even with maximal enlargement. Each subject outline was traced at least twice with the planimeter and the ball outline was traced at least five times. In each instance measured areas for the two subjects were averaged. The multiplying factors were derived from ball diameter data obtained before and after photography each day. Ten measurements were taken each time with a large vernier caliper and an average (obtained from 20 values) calculated for each series of photographs. The ball was spherical to within 2% and remained a constant size (cross-sectional area of 212.1 square inches $\pm 1\%$) throughout the study.

Some photographs of the wet-cold and hot-weather uniforms were not measured, since it became obvious that the effective areas could be satisfactorily obtained by interpolation. Regular changes with angle were

Figure 1. Typical photograph taken for determination of effective area (Arctic uniform, camera at 30° with horizontal)

a. Sitting

b. Standing

c. Walking

d. Prone

Figure 2. Illustrations of positions assumed by subjects

observed for each pose or view (front, side, rear or overhead) in the Arctic uniform, and for those series in the hot-weather uniform which were measured. The difference caused by a 15° change in angle was often smaller than between the two subject areas in the same photograph; this was due to unavoidable differences in pose and clothing arrangement. For this reason, photographs of the hot-weather uniform at 30° and 60° were not measured. The complete series of photographs with the wet-cold uniform (this uniform was handled last) was considered predictable and only sufficient measurements were made to provide a basis for interpolation.

4. Results

Broken line curves of effective area versus solar angle are plotted for each subject position, by uniform and view, in Figures 3 to 6 inclusive. Only the measured values are plotted in these figures.

Values for sitting men (Fig. 3) show that the effective area in a given uniform is practically independent of either the angle or direction of the sunlight except when the sun is directly overhead. Up to 75°, the values vary only from 0.43 to 0.50 m^2 with the Arctic uniform, and from 0.37 to 0.41 m^2 with the hot-weather uniform. In effect, the sitting man acts somewhat like a sphere, presenting the same cross section whether the sun is at front, side, etc.

The results for standing and walking men (Figs. 4 and 5) are very similar both with the sun at the front and with the sun at the rear. With the Arctic uniform, the front view area decreased with angle (15° to 75°) from 0.89 m^2 to 0.69 m^2, and the rear view area from 0.82 m^2 to 0.75 m^2 (walking) or 0.71 m^2 (standing). The higher values for front exposure are presumably the result of frontward projections, such as the feet and parka ruff. Values for side exposures are quite different when subject was standing but only slightly different when subject was in a walking position, where the arms are partly outside the torso silhouette and the two legs are seen separately.

The same observations can be made for the hot-weather uniform, although there are more points of difference than with the Arctic. Standing and walking areas are the same (within 0.04 m^2) for corresponding front and rear exposures (except at 15°) and vary only between 0.57 m^2 and 0.70 m^2. Side exposures show lower values for standing than for walking, for the same reasons as noted for the Arctic uniform.

Areas for prone men (Fig. 6) follow a different pattern, increasing with an increase in angle and changing more rapidly than for the other poses. The curves are not simply the reverse of those for standing men, as one might imagine, considering that the two positions are 90° different. In the prone position, the elbows are extended to the side with the hands under the head, thus greatly reducing the front view area, especially at

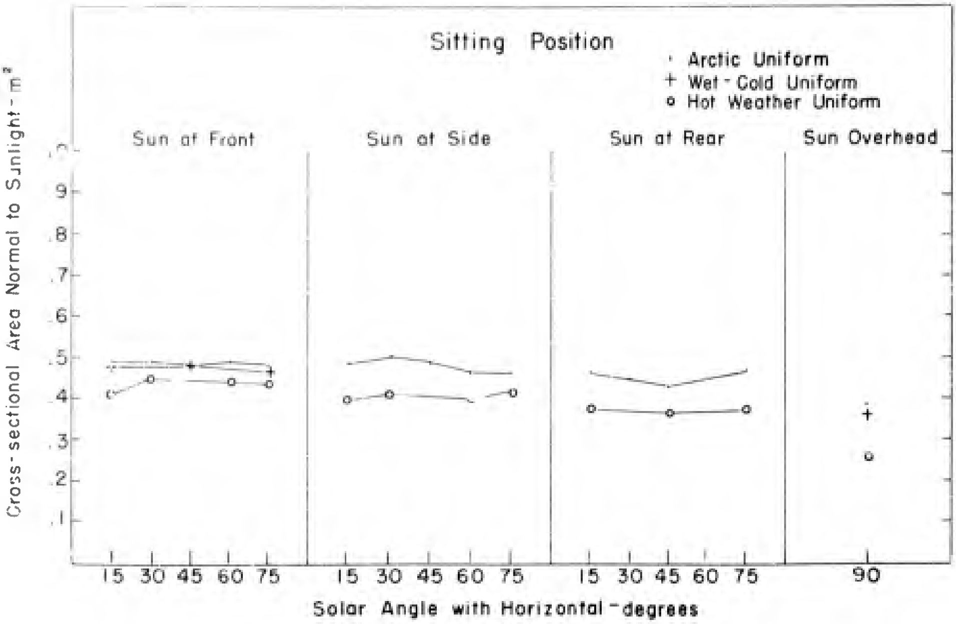

Figure 3. Effective area values for sitting position

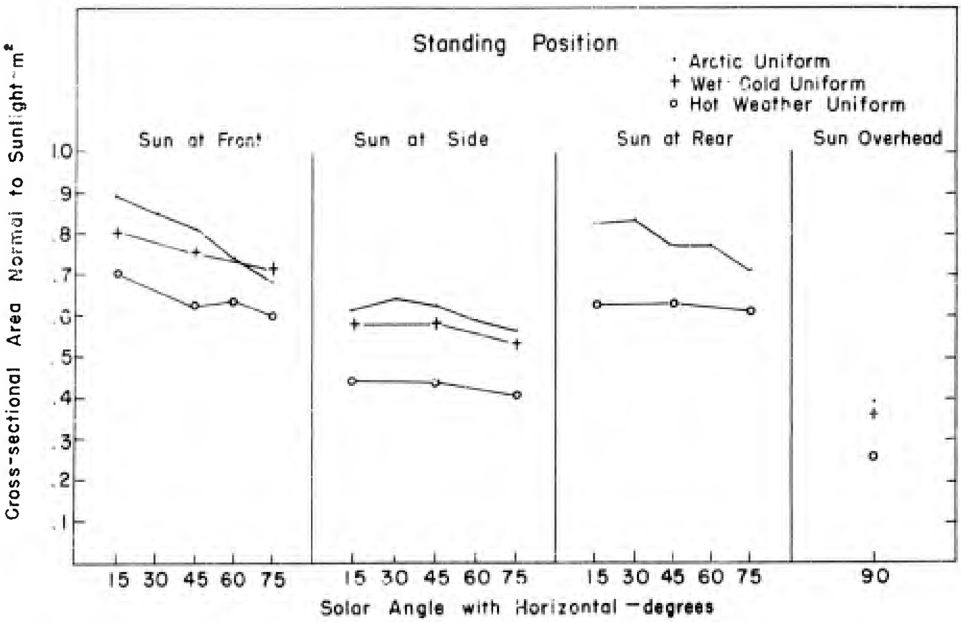

Figure 4. Effective area values for standing position

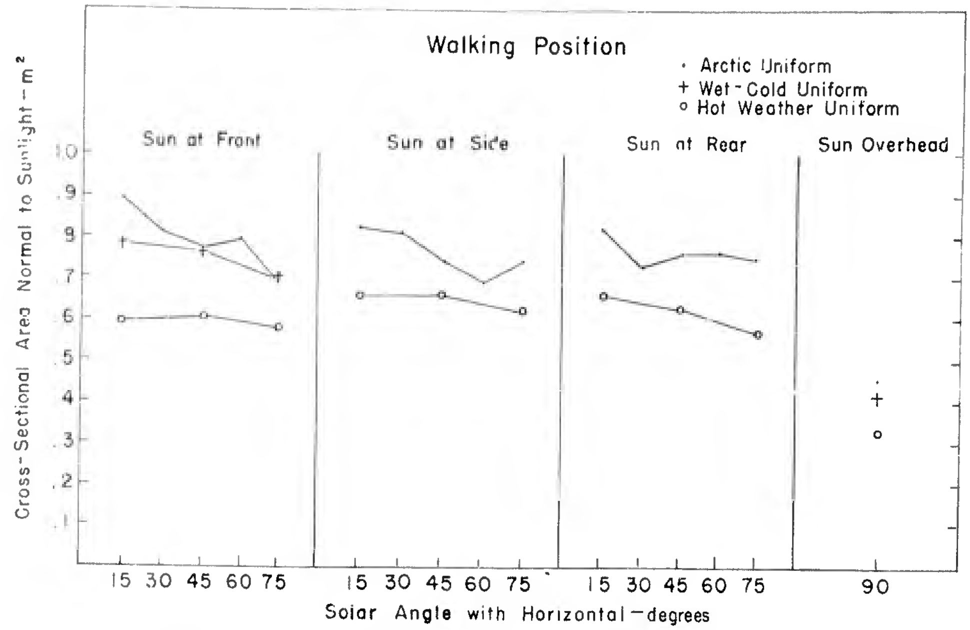

Figure 5. Effective area values for walking position

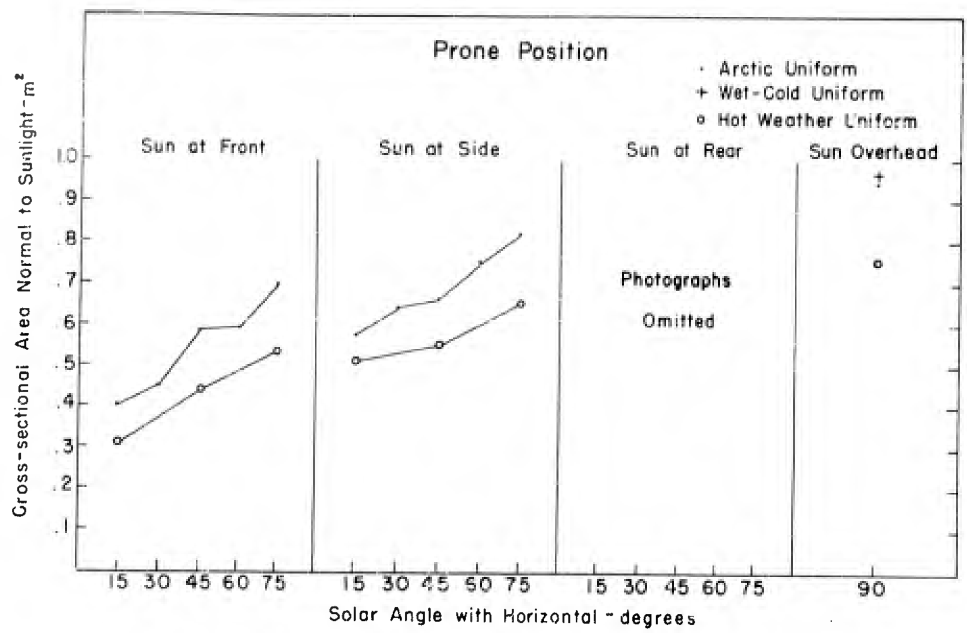

Figure 6. Effective area values for prone position

small angles, as shown in Figure 2d. On the other hand, the side view area in the prone position is larger than in the standing position, mostly because this view is actually a combination of both the side and rear views of the standing man.

Considering the dimensions of the respective uniforms, the available results on the wet-cold uniform are about as expected. They fall approximately 1/3 of the way between values for Arctic and hot-weather uniforms and approximately parallel them. This consistent behavior and the considerations set forth in the next paragraph make interpolation of the missing results entirely logical and justified.

5. Standard values of effective area

The individual results are not readily applicable to men who are constantly changing position. This difficulty can, however, be resolved by grouping those combinations of solar angle and direction for which the effective areas in a given pose and uniform are similar. Only a few groupings are necessary, since small differences in effective area are unimportant to the man; this is shown in the following calculations. Assume still air conditions, clothing insulation to be 4 clo, air insulation to be 0.6 clo, and complete absorption of solar radiation at the outer surface of the clothing. The efficiency is then 13% and this will be a maximum since, as wind speed increases, air insulation falls more rapidly than clothing insulation. Assuming an incident radiation of 1.5 langleys (900 kg-cal/m^2/hr) and absorption of 70%, the heating effect on the man per square meter of effective area is 0.13 x 0.7 x 900 or 82 kg-cal/hr. A change of 0.12 m^2 in effective area will produce a change in heating of only about 10 kg-cal/hr per man, which is relatively unimportant. This is a maximal effect and such a change in area will be even less important in a wind.

If a difference of 10 kg-cal/hr is not considered important, the allowable tolerance in effective area is ± 0.12 m^2 for the Arctic uniform. In several instances, this allowance is larger than changes with solar angle or direction, permitting the use of a single value for a complete curve or series of curves. For example, all values for men sitting in the Arctic uniform are between 0.43 and 0.50 m^2 and a median value of 0.46 m^2 may represent them since an error of only $\pm .04$ m^2 is possible. (An exception is when the sun is directly overhead (0.38 m^2) but it should be remembered that the sun cannot be overhead unless the latitude is less than 23°, and Arctic uniforms are not normally worn in tropical or subtropical latitudes.)

Results of groupings within the stated limits for the Arctic uniform are given in Table I.

Similar calculations show that for the hot-weather uniform, the allowable variation in effective area is ± 0.05 m^2. Standard values for this

uniform and for the wet-cold uniform are also given in Table I. The values for the latter were obtained by interpolating 1/3 of the way between values for Arctic and hot-weather uniforms. Individual values with the sun directly overhead have been excluded, since they are not readily grouped, and moreover, they are not usually involved.

TABLE I
STANDARD VALUES OF EFFECTIVE AREA (m^2)

Position	Direction of Sunlight	Uniform Arctic	Uniform Wet-cold*	Uniform Hot-weather
Sitting	Any direction	0.46	0.44	0.40
Standing	From front or rear	0.79	0.74	0.65
	From side	0.60	0.55**	0.42
Walking	Any direction	0.79	0.73	0.62
Prone	From front, 15° to 45°	0.50	0.46	0.38
	From front, 45° to 75°	0.64	0.60	0.49
	From side, 15° to 75°	0.70	0.66	--
	From side, 15° to 45°	--	--	0.53
	From side, 45° to 75°	--	--	0.60

*Interpolated values for wet-cold uniform except as noted
**Measured

Using this table, a representative value for effective area in any of the three uniforms can be easily determined even when the man's activity is varying. Standing and walking values are similar (except with the sun from the side) eliminating the need to know the percentage of time spent walking or the direction of sunlight. Sitting values are quite different, but the duration of sedentary periods is usually known (rest periods and the like). Prone areas are in a third distinct group but this position is not often taken, except on maneuvers, etc., where an average of walking and prone values will suffice.

6. Discussion

It must be reemphasized that effective area data are only a starting point for estimating solar heating on the clothed man. They apply to direct incident radiation but not to radiation reflected from the ground, which comes from many directions. The latter must be estimated from ground reflection data on the basis of geometrical considerations. With incident radiation known, the percentage absorbed by the clothing and the relative effect at skin level must still be established before the solar heating effect is known. The former may usually be estimated using fabric

reflectance data. Relative effect at skin level, or efficiency, is not simply defined, since it depends on depth of radiation absorption and on such variables as wind speed and body movement. With heavy clothing such as the Arctic or wet-cold uniforms, it suffices to assume absorption at the surface, and efficiency may be calculated using the expression (3)

$$E = \frac{I_a}{I_{cl}+I_a}$$

where I_a is the insulation of the surface air layer and I_{cl} the insulation of the clothing. Adequate information is available in the literature to permit assumption of representative values for I_a and I_{cl} at any wind speed and activity. Efficiency is not so easily established for the hot-weather uniform, because of the possibility that radiation penetrates into the fabric before absorption; this would raise efficiency above that calculated from I_a and I_{cl}. Recent results from measuring sitting men indicated an average efficiency of 35% with winds of 2 to 12 mph; this value may be different for walking men but can be used as a first approximation until other data become available.

It is interesting to calculate the solar heating in an Arctic uniform to illustrate the benefits of sunlight in the cold. An effective area of 0.46 m^2 was used, assuming a sitting man. Solar intensity was taken as 600 kg-cal/m^2/hr and percent absorption as 70%. With 5 mph wind, efficiency is about 10%, giving a heating from direct radiation of 19 kg-cal/hr. Reflected sunlight from the terrain (assuming 50% reflected) apparently contributes a like amount, making the total 38 kg-cal/hr, which is equivalent to an air temperature rise of 20 F degrees.

In conclusion, it should also be noted that sunlight plays an important beneficial role in alleviating the sensation of damp cold. Detailed discussion of this point may be found elsewhere (6).

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